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AD NUMBER
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30 Nov 1969 DoDD 5200.10; 30 Nov 1969 BUAER

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The
Antenna
Laboratory

Department of Electrical Engineering

FINAL ENGINEERING REPORT
12 November 1956 to 11 November 1957

ANTENNA RESEARCH

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REPORT 723-5

R E P O R T
by
THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION
COLUMBUS 10, OHIO

Cooperator . . . . North American Aviation, Inc.
Columbus Division
4300 East Fifth Avenue
Columbus 16, Ohio

Contract . . . . NOa(s)56-978

Investigation of . . . . Antenna Research

Subject of Report . . . . Final Engineering Report
12 November 1956 to 11 November 1957

Submitted by . . . . Antenna Laboratory
Department of Electrical Engineering

Date . . . . 15 November 1957

~~CONFIDENTIAL~~

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FINAL ENGINEERING REPORT

I. INVESTIGATION OF LOSS CHARACTERISTICS OF COMMERCIAL LOW-PASS FILTERS

A manual in the form of a technical report[2] was written to assist in the specification, selection, and testing of commercially available low-pass filters for certain applications.

General loss and rejection properties of high-attenuation filters were discussed and a number of criteria for judging the characteristics of such filters were presented.

Test procedures were described for determining the characteristics of the filters and a few tests were made to illustrate these procedures.

II. ISOLATION OF ANTENNA SYSTEMS

A number of antenna isolation methods were considered.[1] These included orthogonal antennas, hybrid junctions in the feed systems, and combinations of the two.

A coaxial hybrid junction (magic "T") was first considered, and a model designed to operate in the neighborhood of 1000 mc was tested over the 900-1300 mc range using stub antennas as loads.[3] The isolation ranged from about thirty to forty db over this frequency range.

The coaxial hybrid junction has two serious disadvantages: (1) it is mechanically difficult to adjust, and (2) in the desired frequency range (in the neighborhood of 100 mc) it would be quite large physically.

As an alternative, a lumped-element, transformer-type hybrid junction[3,4] was constructed and tested. This had the advantages of small size, inherently broadband operation, and relative ease of balancing adjustments. Capacitance coupling between the two inputs is eliminated by constructing the transformer input loop of shielded wire with the shield grounded.

With this junction, a uniform isolation, between 40 and 50 db, was obtained over a frequency range of 65 to 150 mc. The insertion loss ranged from one to two decibels for the tapped input and from four to ten decibels for the transformer. (See Fig. 8 of Ref.4.)

The isolation can be peaked up to about 70 db at a particular frequency by careful adjustments. Figure 1 shows the results of such an adjustment. The isolation remains above 40 db up to about 215 mc and rises to about 68 db at 175 mc. However, the insertion loss also hits a peak of 15 db at 200 mc.

The insertion loss of the transformer seems to be somewhat of a limiting factor. Some effort was made to reduce this, but under the best conditions the loss in any transformer-coupled circuit could not be reduced below two decibels.

III. CIRCULARLY POLARIZED X-BAND ANTENNAS

It is desired to develop techniques for designing circularly polarized, flush-mounted, broad-band antennas in the neighborhood of X-band with about a 60° beam width and a given beam direction which may range from the normal to within 30° of the ground plane.

With so many pattern requirements as well as the additional impedance and efficiency problems, it seems advisable to break the problem into smaller parts, even though these will not be entirely independent.

The first problem to be considered was that of beam tilt. Here again the problem has been subdivided into two parts; the characteristics of each of the two component orthogonal linear polarizations of the radiated circular polarization. One linear component is in, or parallel to, the plane perpendicular to the ground plane and which contains the axis of the beam. This is the plane (which we shall call the "tilt plane" for convenience) in which the patterns of the tilted beam are taken. The other linear component of radiation is perpendicular to the tilt plane, and hence is parallel to the ground plane.

Each of the linear polarization components is due to the corresponding electric field in the waveguide which feeds the horn, and is independent of the other, so that the pattern and impedance characteristics of each component of polarization can be measured separately by feeding the waveguide and hence the horn with the desired polarization. Circular polarization can then be obtained by exciting the proper electric field components in the waveguide.

A dielectric prism in the mouth of a horn in a ground plane was selected as a means of tilting the beam. Such a "lens" should be inherently broadband since dielectric material, in general, is
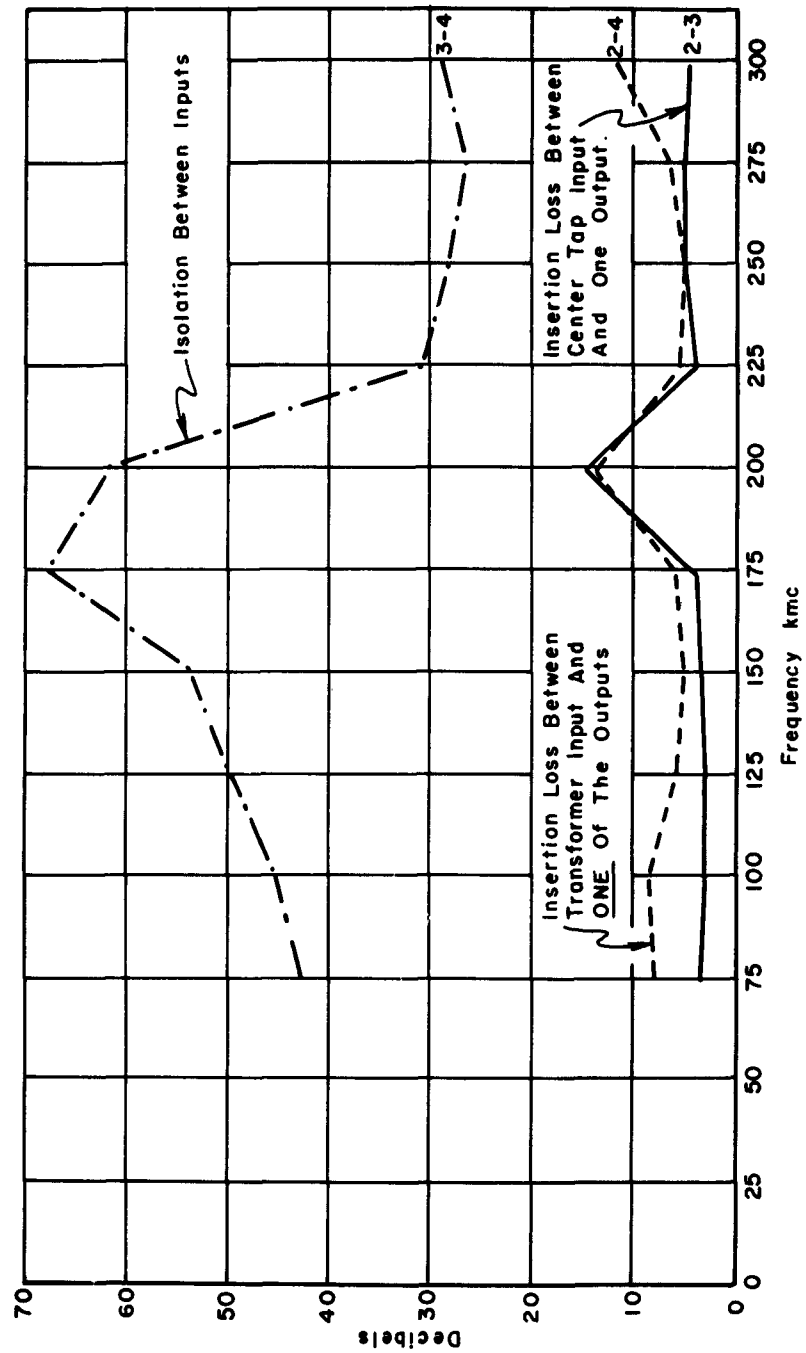
Fig. 1. Insertion losses and isolation of a transformer
type hybrid junction.

quite isotropic and the permittivity is constant over a range of frequencies. The angle of the beam tilt may be estimated by using optical methods as follows.

At the "exterior" interface, by Abbe's law of sines:

(1) $\qquad \sin \delta = \sqrt{\epsilon_r} \, \sin \gamma$.

Also, at the "interior" interface,

(2) $\qquad \sin \alpha = \sqrt{\epsilon_r} \, \sin \beta$

(3) $\qquad\qquad = \sqrt{\epsilon_r} \, \sin (\alpha - \gamma)$

(4) $\qquad\qquad = \sqrt{\epsilon_r} \, \sin \alpha \cos \gamma - \sqrt{\epsilon_r} \, \sin \gamma \cos \alpha$

(5) $\qquad\qquad = \sqrt{\epsilon_r} \, \sin \alpha \cos \gamma - \sin \delta \, \cos \alpha$,

where (5) follows from the substitution of (1) into (4). Dividing (5) by sin α yields

(6) $\qquad 1 = \sqrt{\epsilon_r} \cos \gamma - \sin \delta \, \cot \alpha$,

which can be put into various forms, such as:

(7) $\qquad \sin \delta = [\sqrt{\epsilon_r} \cos \gamma - 1] \, \tan \alpha$

and

(8) $\qquad \tan \alpha = \dfrac{\sin \delta}{\sqrt{\epsilon_r} \cos \gamma - 1}$.

For small angles of tilt, γ is also small, making cos γ $\sim$ 1, and permitting the following approximations:

(9) $\qquad \sin \delta \sim [\sqrt{\epsilon_r} - 1] \, \tan \alpha$

and

(10)
$$\tan \alpha \simeq \frac{\sin \delta}{\sqrt{\epsilon_r - 1}} \; .$$

It is emphasized that these approximations, (9) and (10), are good only if the beam tilt δ is small, and that for large tilts one of the exact expressions, (6), (7), or (8), must be used. Since these are transcendental equations they cannot be easily solved explicitly, but a number of calculating curves can be easily constructed by substituting selected values in the equations and computing the corresponding points.

The first antenna tried consisted of a polystyrene prism with a 30° angle in the mouth of a horn having a 60° flare angle and a 3.75-inch aperture mounted in a 17-inch square ground plane.[4] The tests showed that the optical approximation of the beam tilt was quite good.

For further tests a sectoral horn with a 60° flare angle and a 3.75-inch x 0.81-inch aperture was mounted in the 17-inch square ground plane. The short dimension (0.81-inch) of the aperture was calculated to give a 60° beam width. Figures 4, 6, 8, 10, 12, and 14 show the corresponding patterns in the plane perpendicular to the tilt plane and through the maximum of the corresponding tilted beam. The "fingers" on some of these patterns in which the polarization has a component perpendicular to the ground plane appear to be caused by diffraction at the edges of the ground plane. The fundamental pattern is still clearly discernable, however.

The other figures up through 18 show the patterns of the tilted beams, in both polarizations, for a number of experimental wedge-shaped prisms inserted into the mouth of the horn. The estimated angle of tilt is also shown in each case for comparison.

In view of the simplicity of design and construction the results are surprisingly good. The patterns show that the beam tilts are in the neighborhood of the optical estimate, and in most cases the beam was well shaped without bad side lobes.
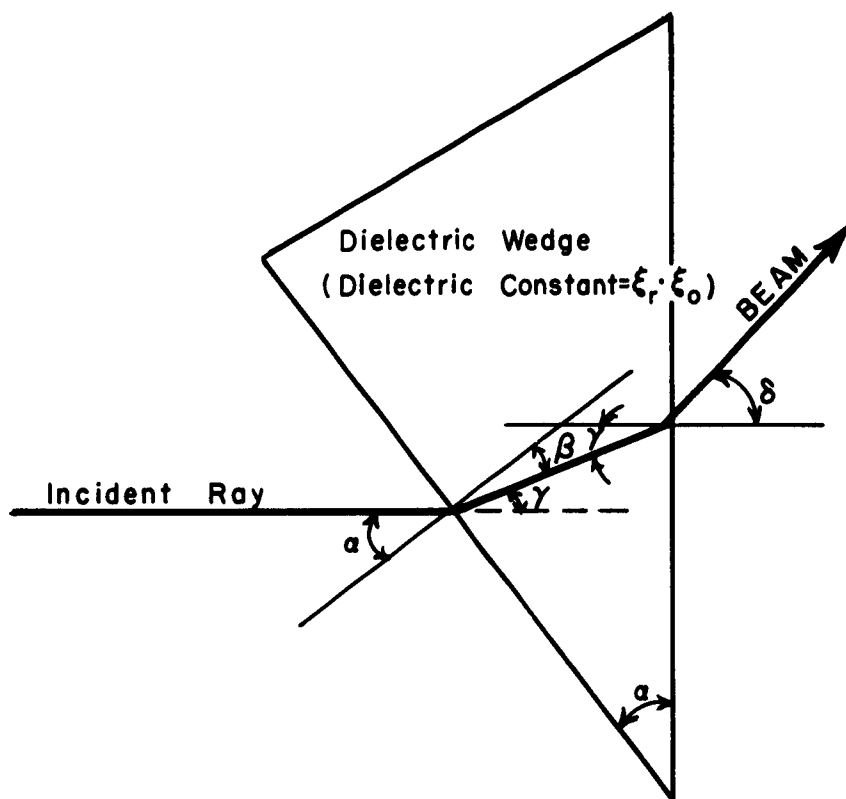
Fig. 2. Beam tilt of an incident ray
by a dielectric wedge with a
wedge angle γ and a dielectric
constant η.

However, in most cases the beams of the two polarizations do not coincide, and both have a tendency to sweep as a function of frequency. At present it is felt that both of these effects are due to reflections which are different for the two polarizations (as a result of the oblique incidence) and result in a difference in the beam directions. The effects of reflections are a function of frequency since the electrical path lengths are also functions of frequency. In this case the problem of stabilizing the two beams and getting them to coincide is really an impedance-matching problem.

In addition, anisotropic lenses can be constructed to adjust the beam tilts of the two polarizations separately.

It is difficult, in general, to obtain a beam close to a ground plane with the polarization parallel to the ground plane. In this antenna this is the polarization perpendicular to the plane of the tilted beam patterns. A survey of the patterns will show that beams of this polarization may be tilted to within 20° of the ground plane with this type of antenna. There is no difficulty in getting beam tilts of this magnitude with the other polarization (which, at these low angles, is perpendicular to the ground plane).

The range of frequencies covered in testing the antenna operation was effectively extended by modeling. The long dimensions of the aperture was reduced from 3.75 inches to 2.81 inches to determine the effect of lower frequencies on the patterns in the tilt plane. The other aperture dimension was maintained at 0.81 inch for mechanical reasons. The effect of this dimension is of minor concern.

The patterns with the smaller horn are shown in Figs. 19 through 22. As expected, the patterns begin breaking up at these simulated lower frequencies (smaller apertures).

The problem of checking the patterns at higher frequencies remains. Other problems remaining are those of impedance matching over the wide range, and combining the beams to obtain circular polarization.

The circular polarization may be obtained by controlling the relative phase and amplitude between the two orthogonal electrical fields in the waveguide feeding the horn.

It is expected that the impedance problem will be much more difficult, and will probably involve a rather extensive investigation which cannot be undertaken within the present contract.

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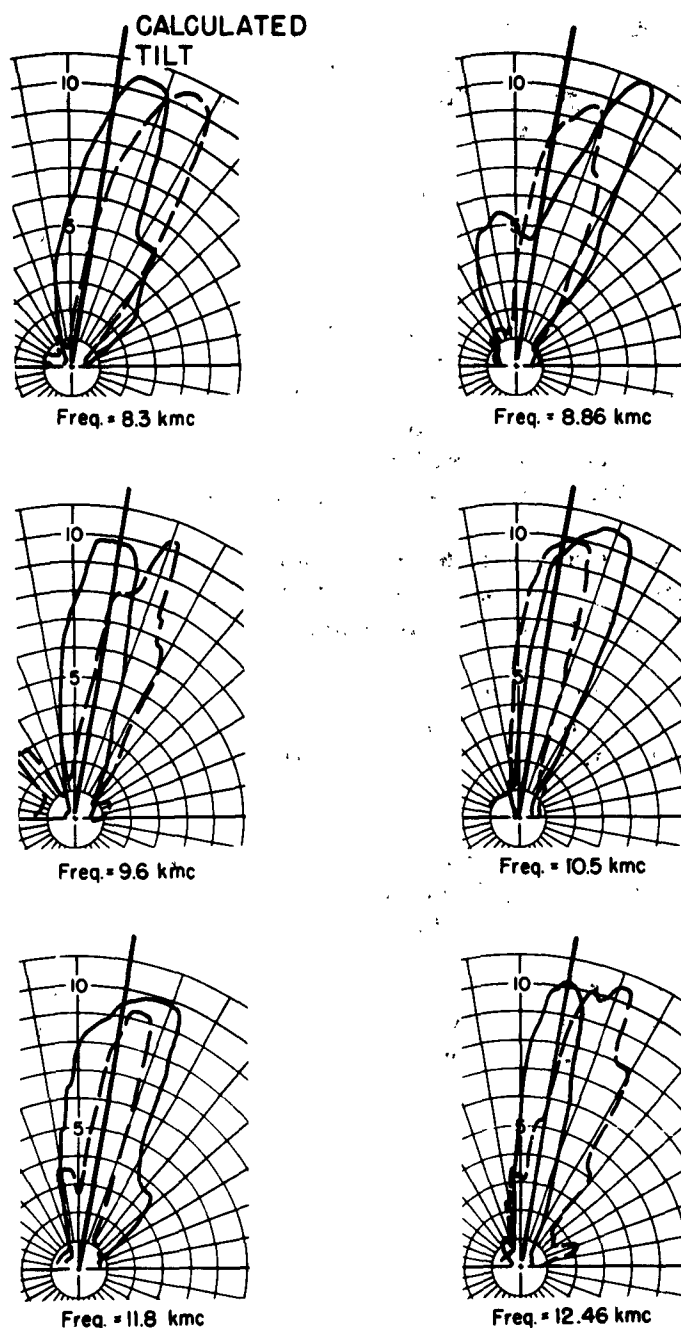
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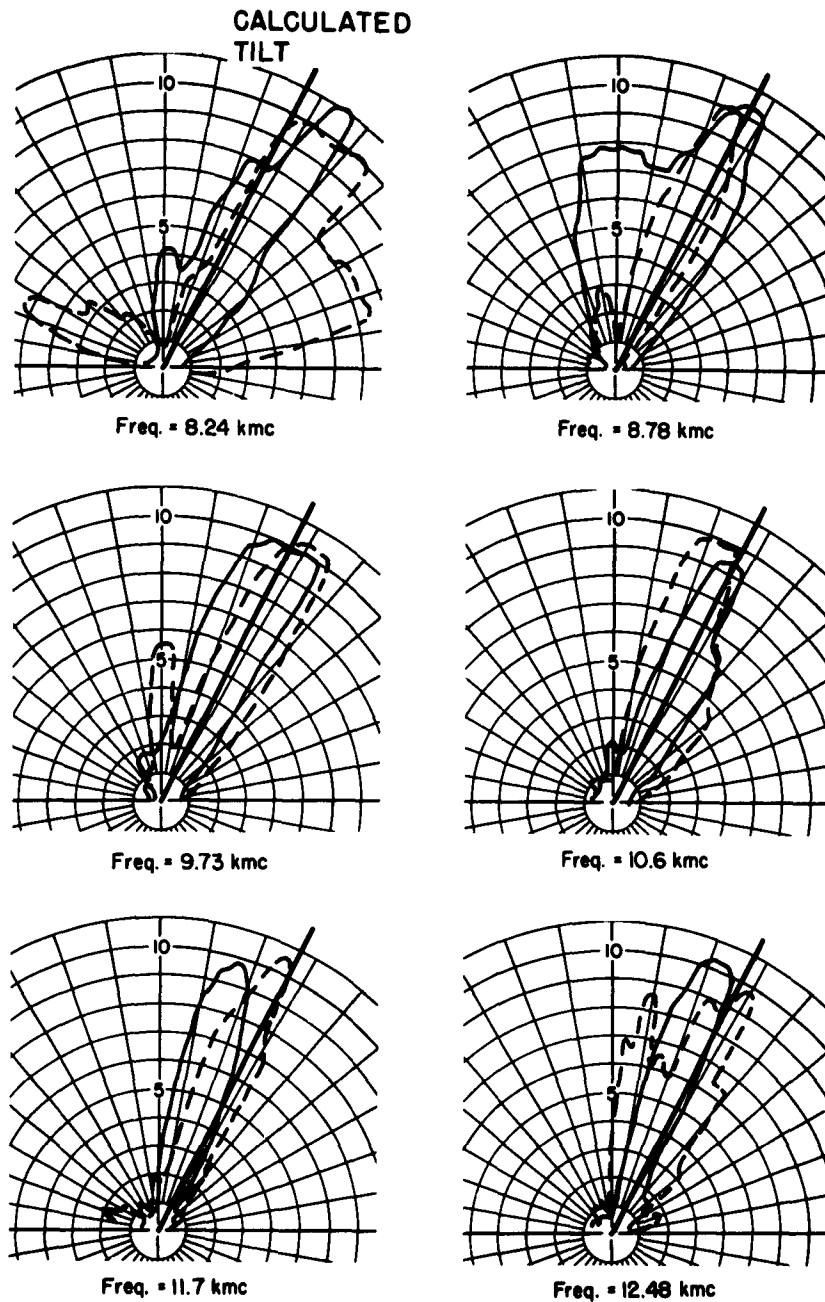Freq. = 9.6 kmc

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Fig. 3. Patterns of the tilted beam obtained with a 14° wedge with a dielectric constant of 4, in a 3.75" x 0.81" aperture fed by a 60° flare sectoral horn. Approximate calculated tilt = 10°. Polarization of solid patterns is normal to the plane of the pattern. Polarization of dashed patterns is in the plane of the pattern.
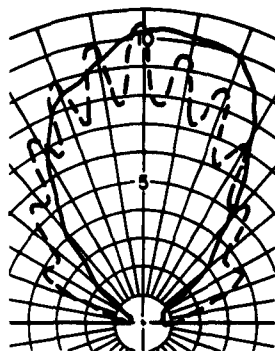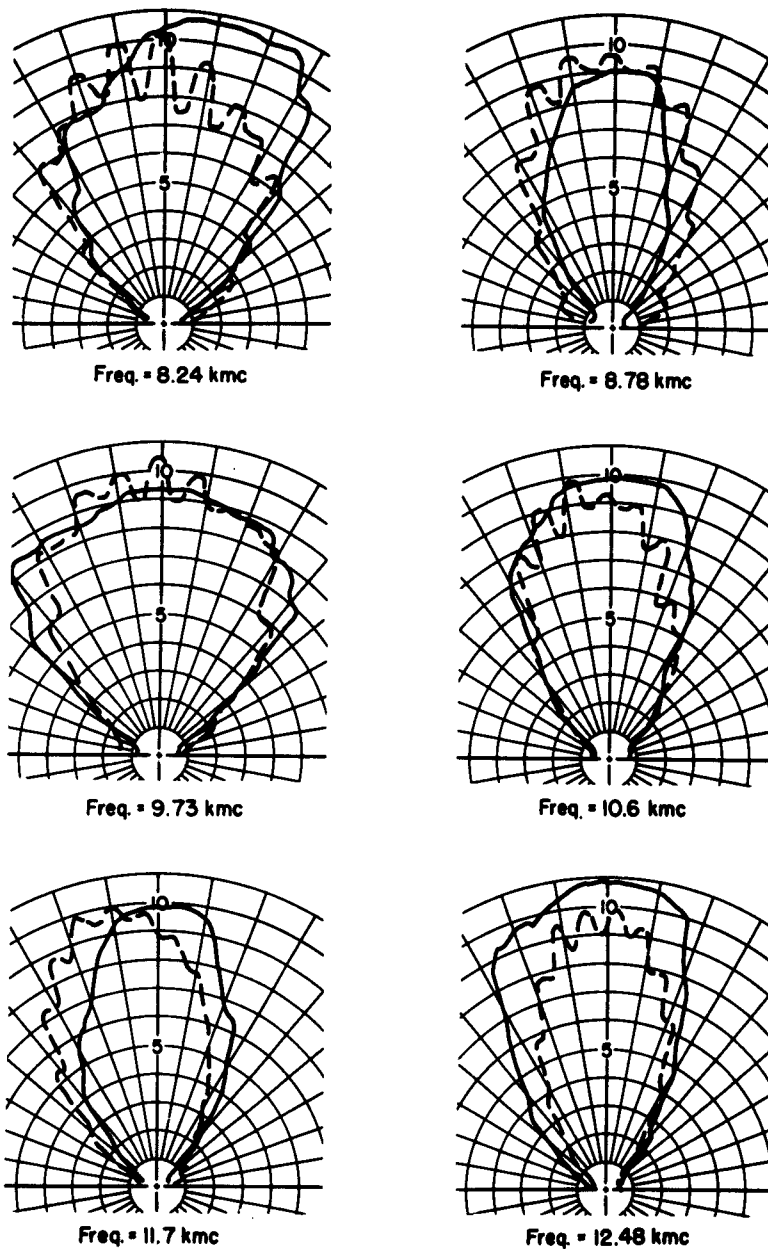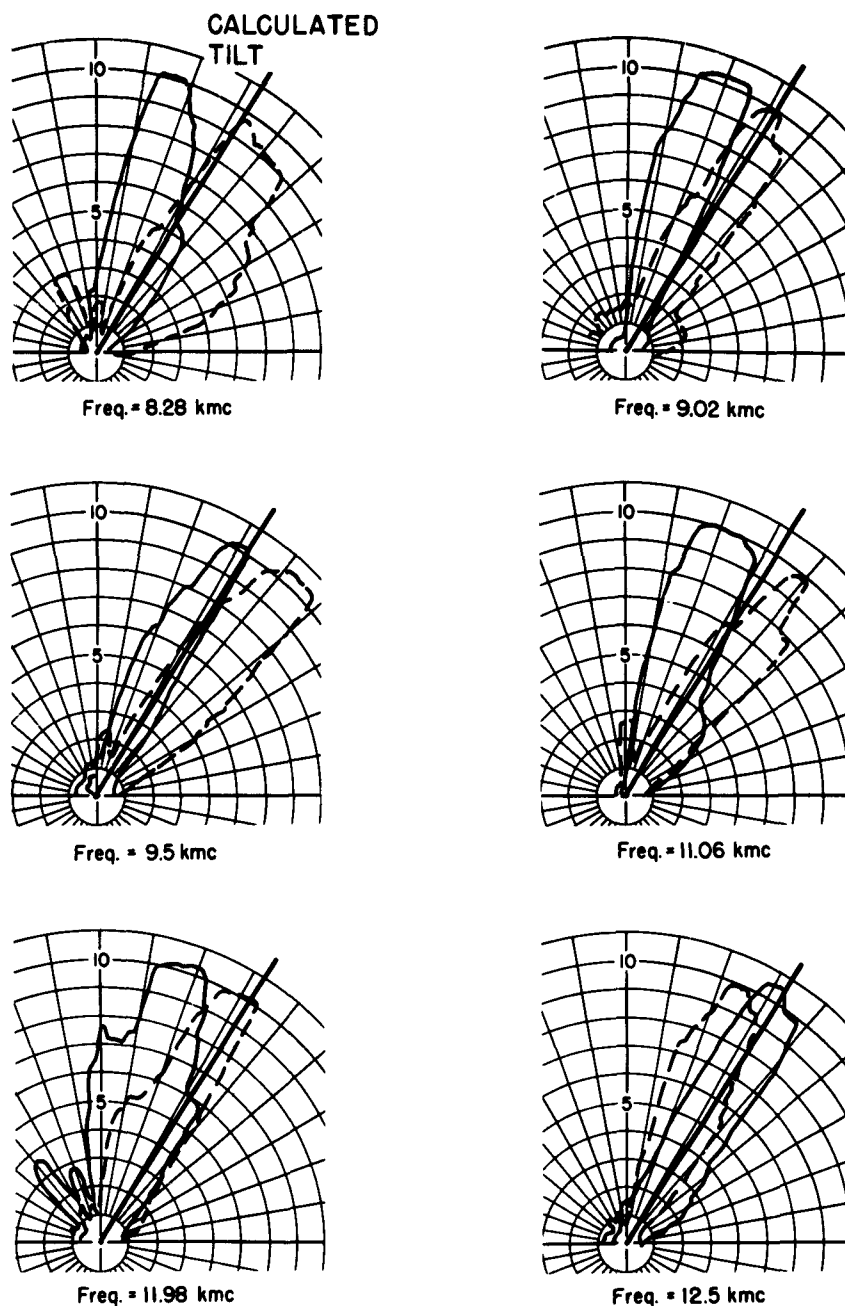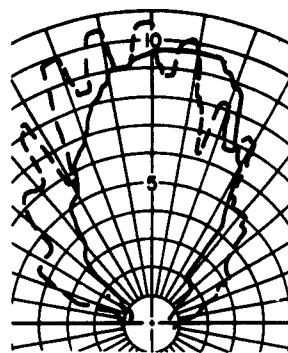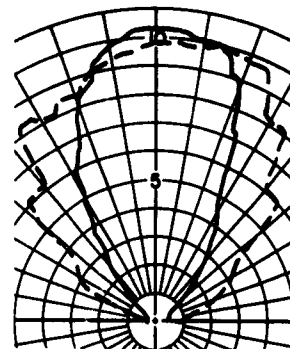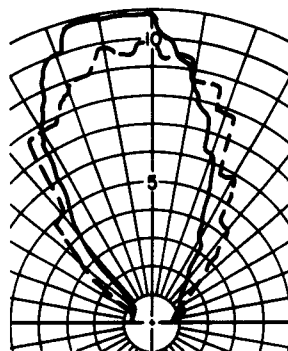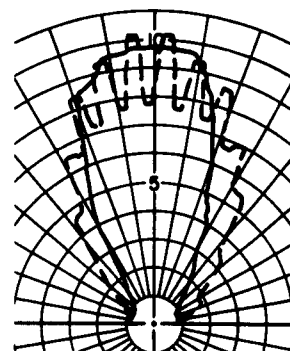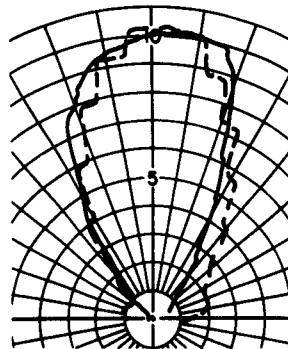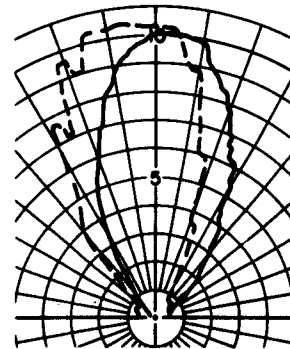
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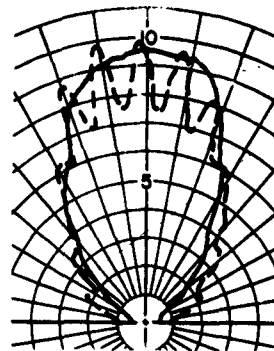
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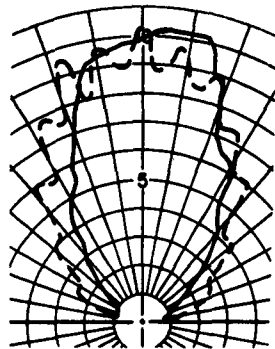
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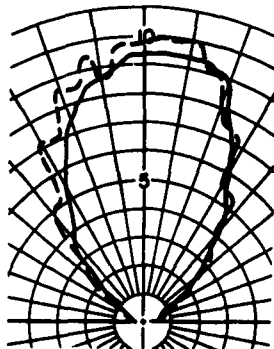
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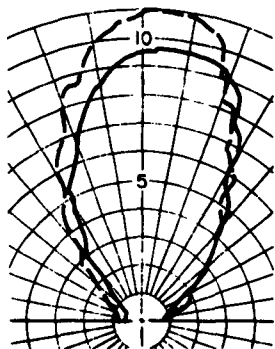
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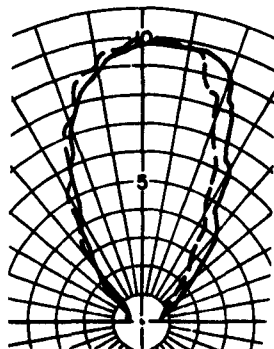
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Fig. 4. Patterns in the plane orthogonal to the plane of tilt obtained with a 14° wedge with a dielectric constant of 4, in a 3.75" x 0.81" aperture fed by a 60° flare sectoral horn. Polarization of solid patterns is normal to the plane of the pattern. Polarization of dash patterns is in the plane of the pattern..

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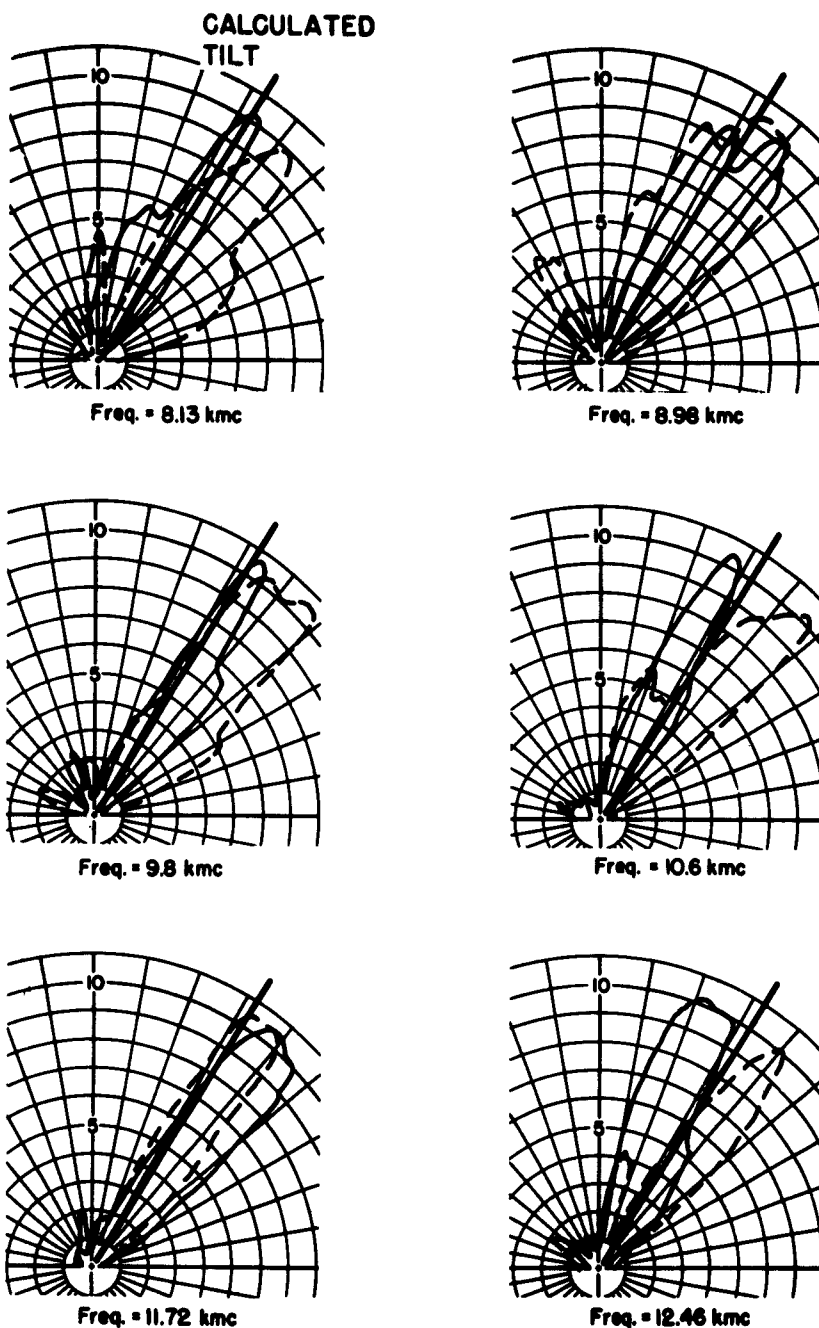Freq. = 9.73 kmc

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Fig. 5. Patterns of the tilted beam obtained with a 14° wedge with a dielectric constant of 8, in a 3.75" x 0.81" aperture fed by a 60° flare sectoral horn. Approximate calculated tilt = 27°. Polarization of solid patterns is normal to the plane of the pattern. Polarization of dash patterns is in the plane of the pattern.
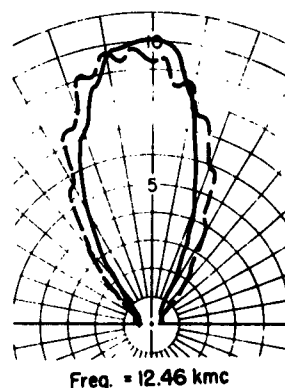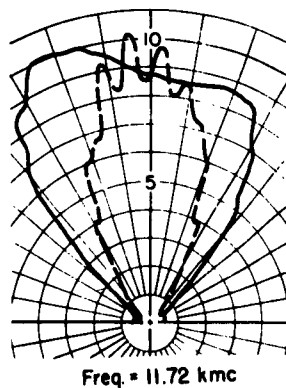
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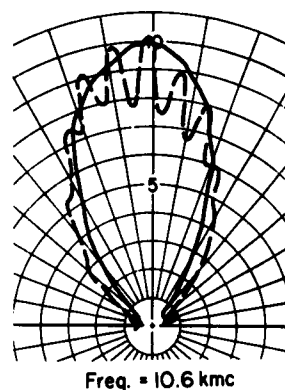
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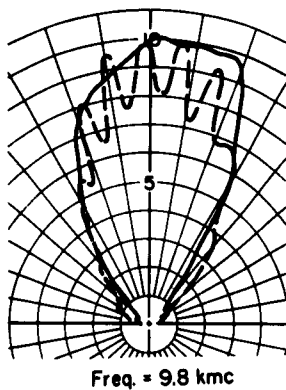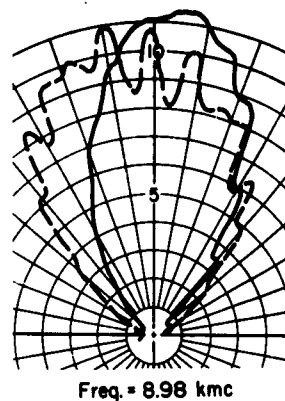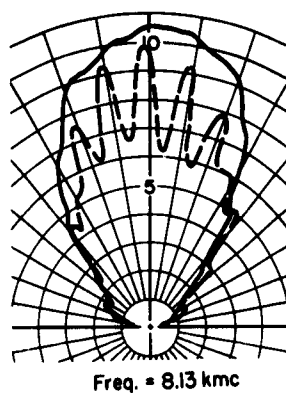
Fig. 6. Patterns in the plane orthogonal to the plane of tilt obtained with a 14° wedge with a dielectric constant of 8 in a 3.75" x 0.81" aperture fed by a 60° flare sectoral horn. Polarization of solid patterns is normal to the plane of the pattern. Polarization of dashed patterns is in the plane of the pattern.

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Fig. 7. Patterns of the tilted beam obtained with a 14° wedge
with a dielectric constant of 10 in a 3.75" x 0.81"
aperture fed by a 60° flare sectoral horn. Approxi-
mate calculated tilt = 32°. Polarization of solid
patterns is normal to the plane of the pattern. Polar-
ization of dashed patterns is in the plane of the pattern.

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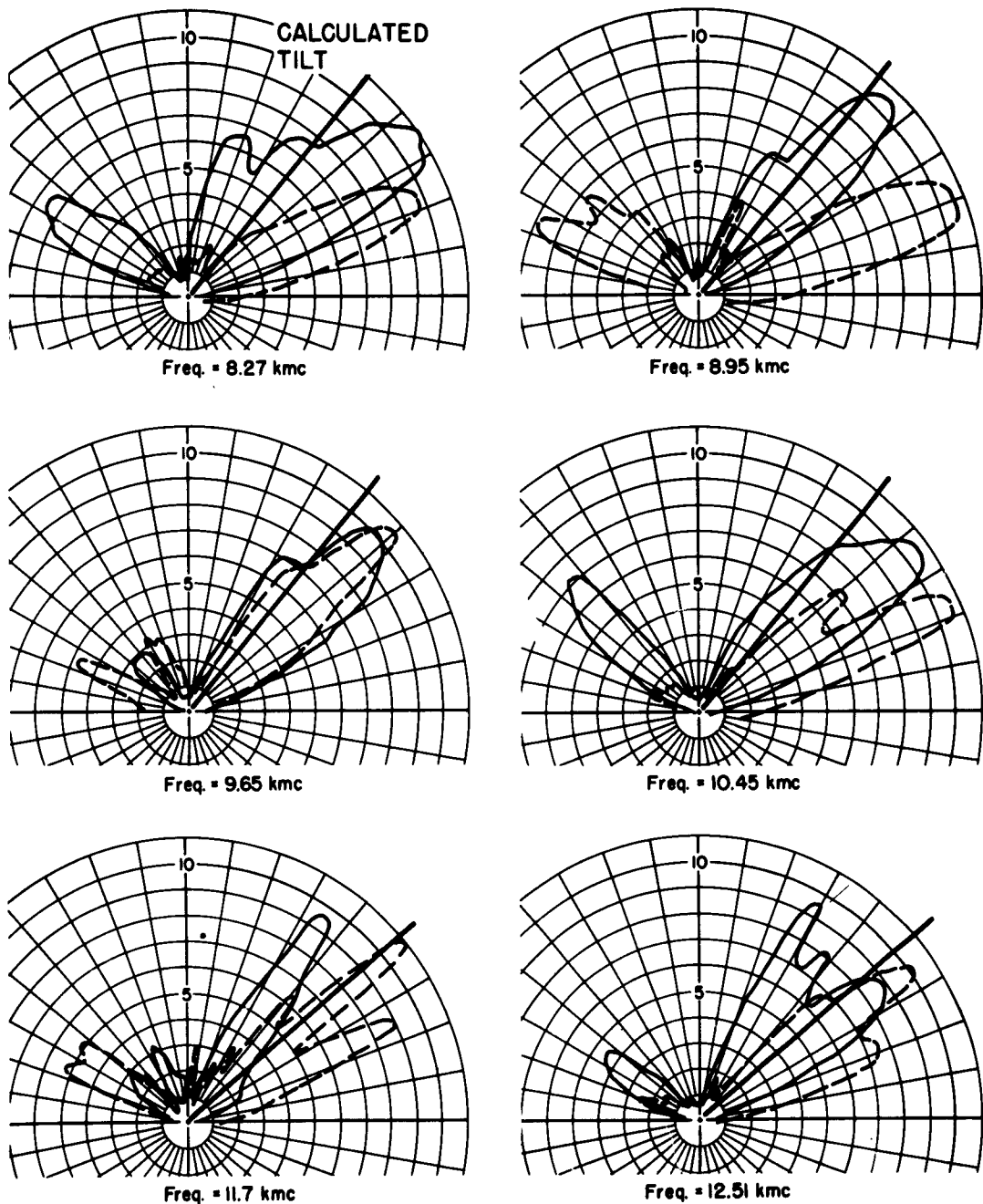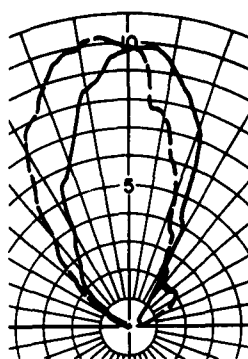
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Fig. 8. Patterns in the plane orthogonal to the plane of tilt
obtained with a 14° wedge with a dielectric constant
of 10 in a 3.75" x 0.81" aperture fed by a 60° flare
sectoral horn. Polarization of solid patterns is
normal to the plane of the pattern. Polarization of
dashed patterns is in the plane of the pattern.

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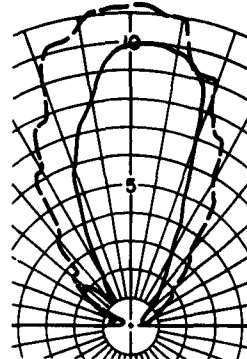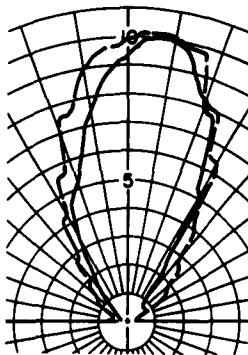
Fig. 9. Patterns of the tilted beam obtained with a 21° wedge with a dielectric constant of 6 in a 3.75" x 0.81" aperture fed by a 60° flare sectoral horn. Approximate calculated tilt = 32°. Polarization of solid patterns is normal to the plane of the pattern. Polarization of dashed patterns is in the plane of the pattern.
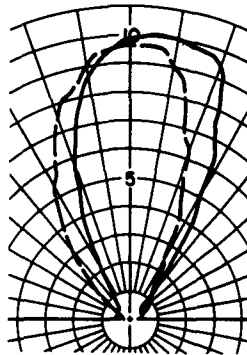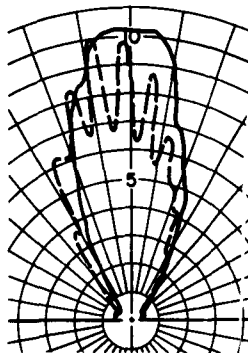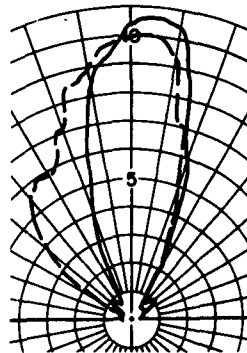
Fig. 10. Patterns in the plane orthogonal to the plane of tilt obtained with a 21° wedge with a dielectric constant of 6 in a 3.75" x 0.81" aperture fed by a 60° flare sectoral horn. Polarization of solid patterns is normal to the plane of the pattern. Polarization of dashed patterns is in the plane of the pattern.
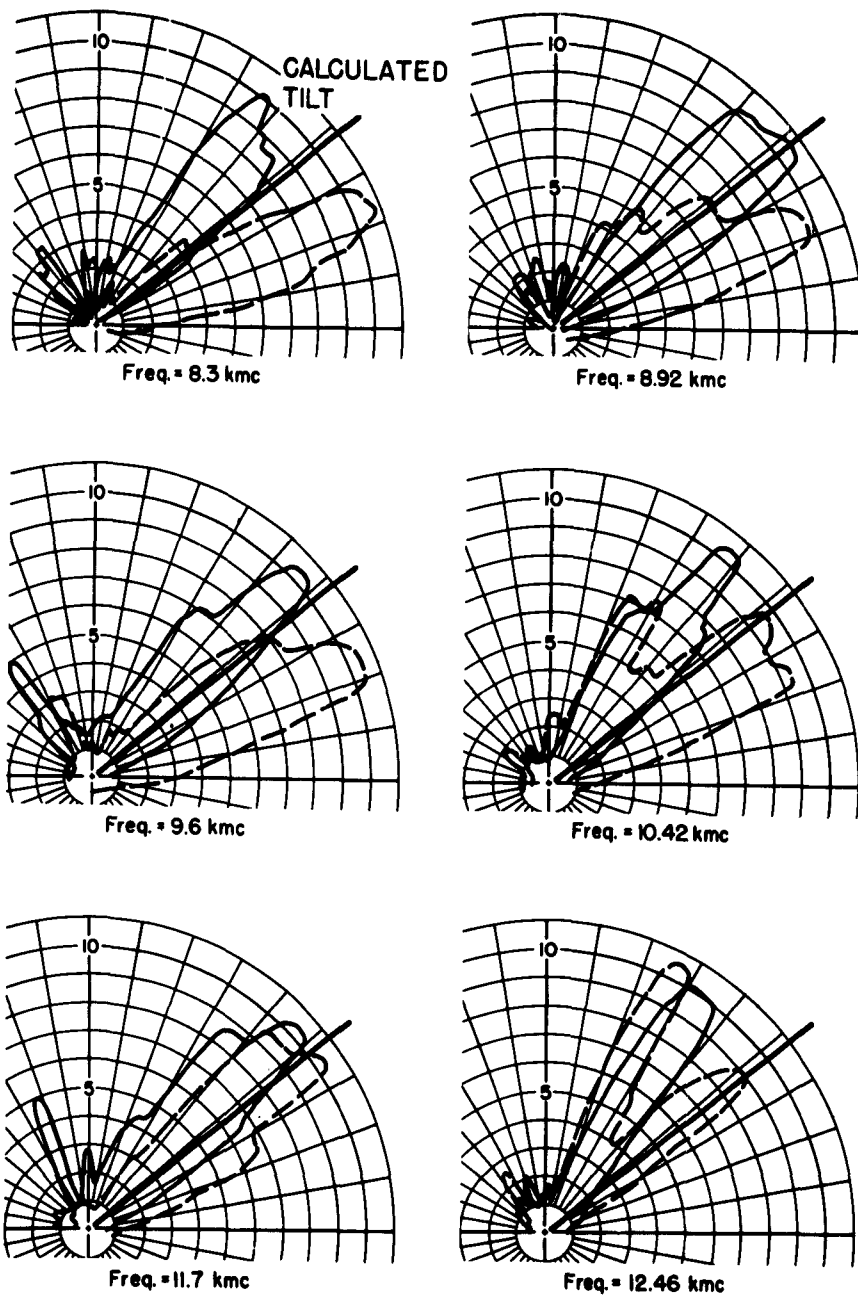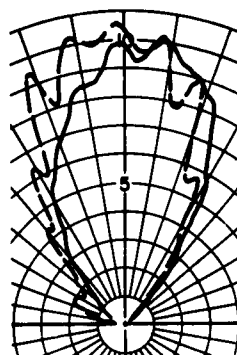
Fig. 11. Patterns of the tilted beam obtained with a 30° wedge with a dielectric constant of 6 in a 3.75" x 0.81" aperture fed by a 60° flare sectoral horn. Approximate calculated tilt = 50°. Polarization of solid patterns is normal to the plane of the pattern. Polarization of dashed patterns is in the plane of the pattern.

Fig. 12. Patterns in the plane orthogonal to the plane of tilt obtained with a 30° wedge with a dielectric constant of 6 in a 3.75" x 0.81" aperture fed by a 60° flare sectoral horn. Polarization of solid patterns is normal to the plane of the pattern. Polarization of dashed patterns is in the plane of the pattern.
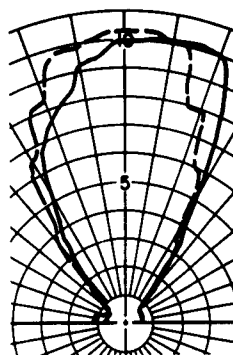
Fig. 13. Patterns of the tilted beam obtained with a 21° wedge with dielectric constant of 10 in a 3.75" x 0.81" aperture fed by a 60° flare sectoral horn. Approximate calculated tilt = 52°. Polarization of solid patterns is normal to the plane of the pattern. Polarization of dashed patterns is in the plane of the pattern.
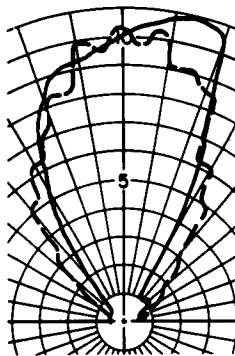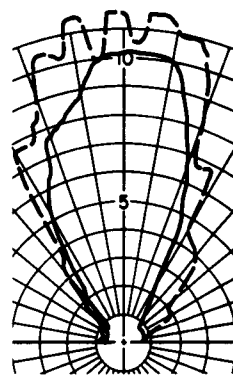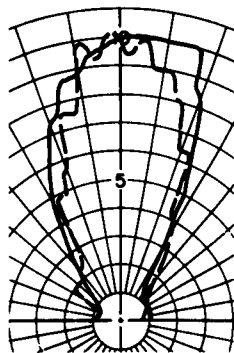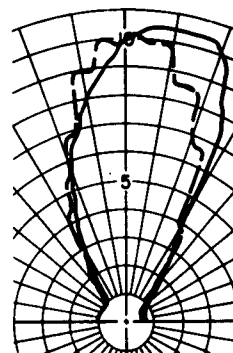
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Fig. 14. Patterns in the plane orthogonal to the plane of tilt
obtained with a 21° wedge with a dielectric constant
of 10 in a 3.75" x 0.81" aperture fed by a 60° flare
sectoral horn. Polarization of solid patterns is
normal to the plane of the pattern. Polarization
of dashed patterns is in the plane of the pattern.

Fig. 15. Patterns of the tilted beam obtained with a 16° wedge
with dielectric constant of 15 in a 3.75" x 0.81"
aperture fed by a 60° flare sectoral horn. Approxi-
mate calculated tilt = 52°. Polarization of solid
patterns is normal to the plane of the pattern. Polar-
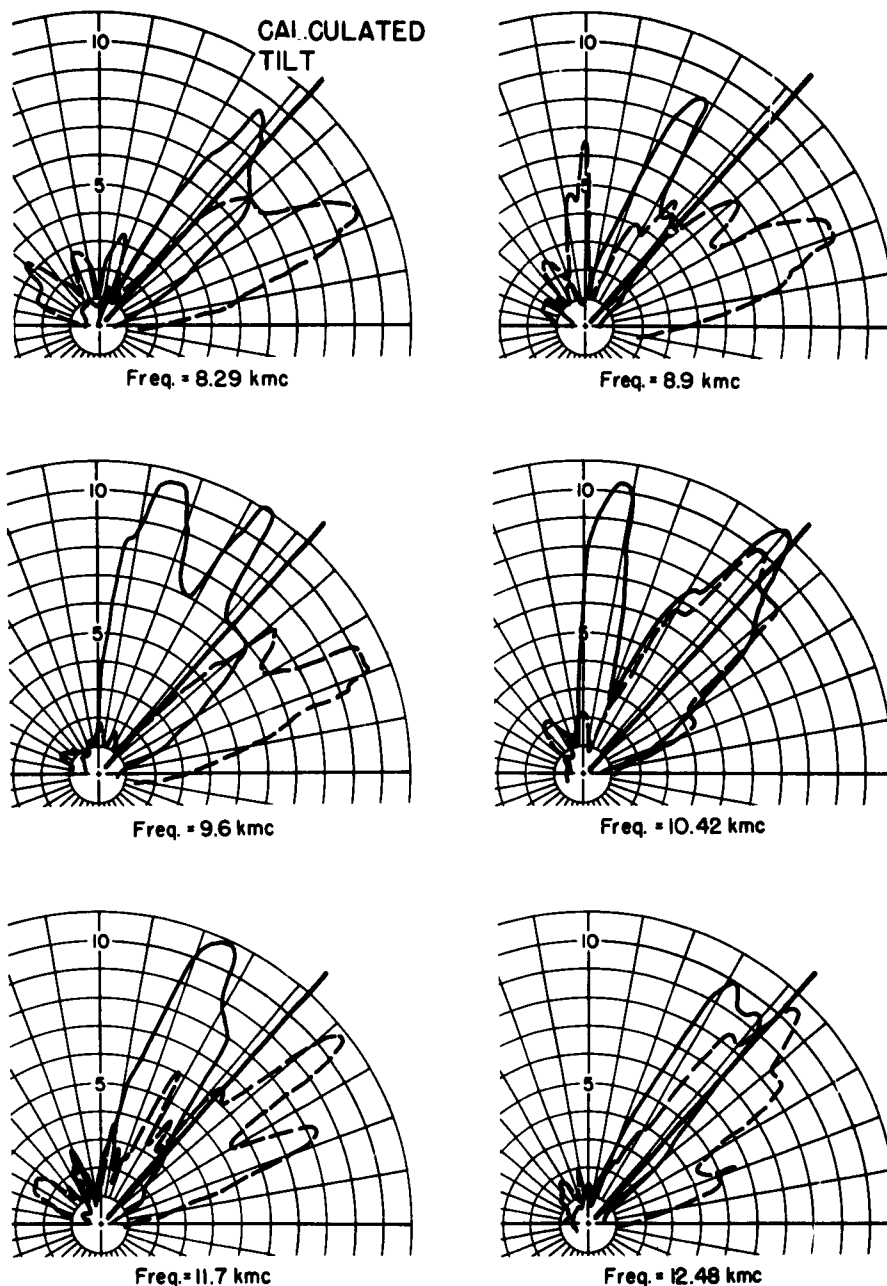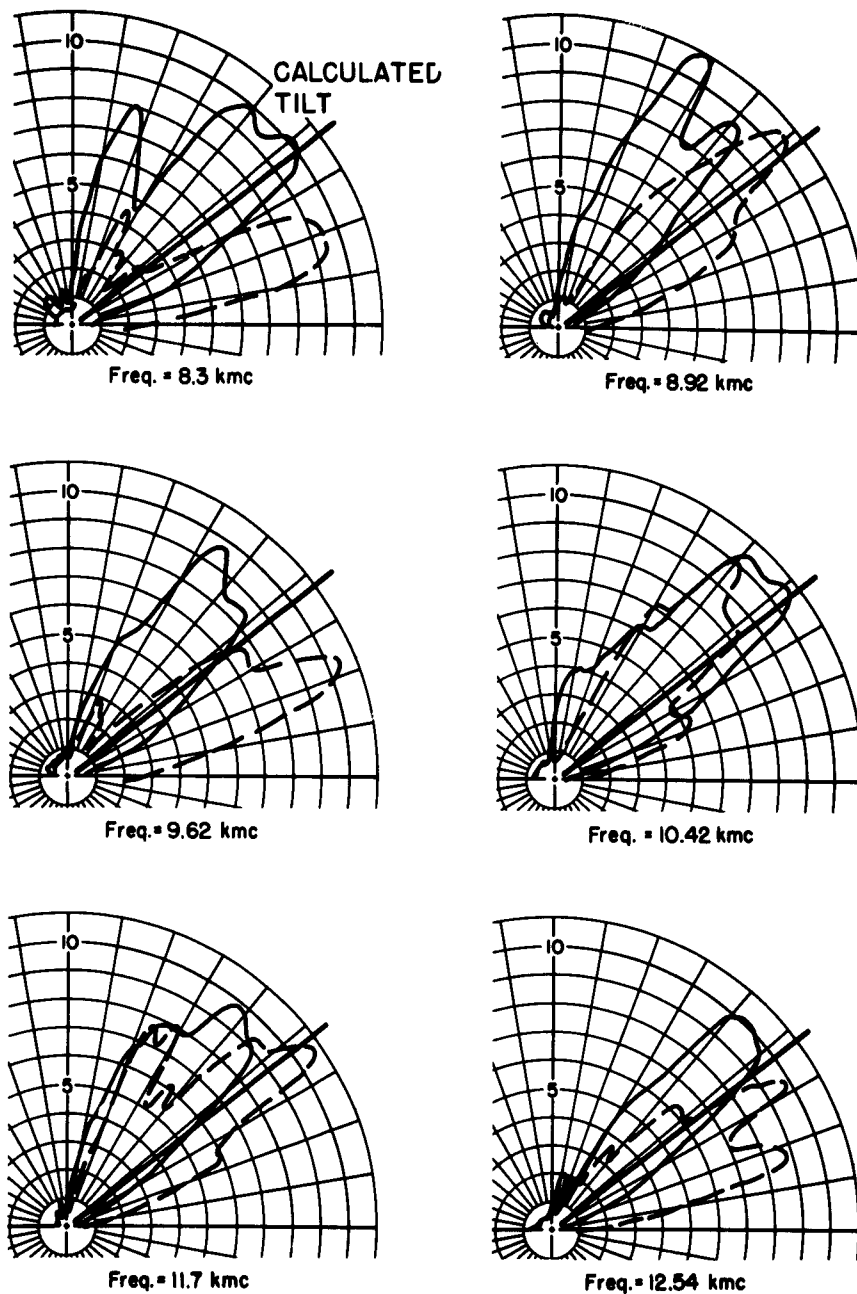ization of dashed patterns is in the plane of the pattern.

Fig. 16. Patterns of the tilted beam obtained with a 13° wedge
with dielectric constant of 20 in a 3.75" x 0.81"
aperture fed by a 60° flare sectoral horn. Approxi-
mate calculated tilt = 52°. Polarization of solid
patterns is normal to the plane of the pattern. Polar-
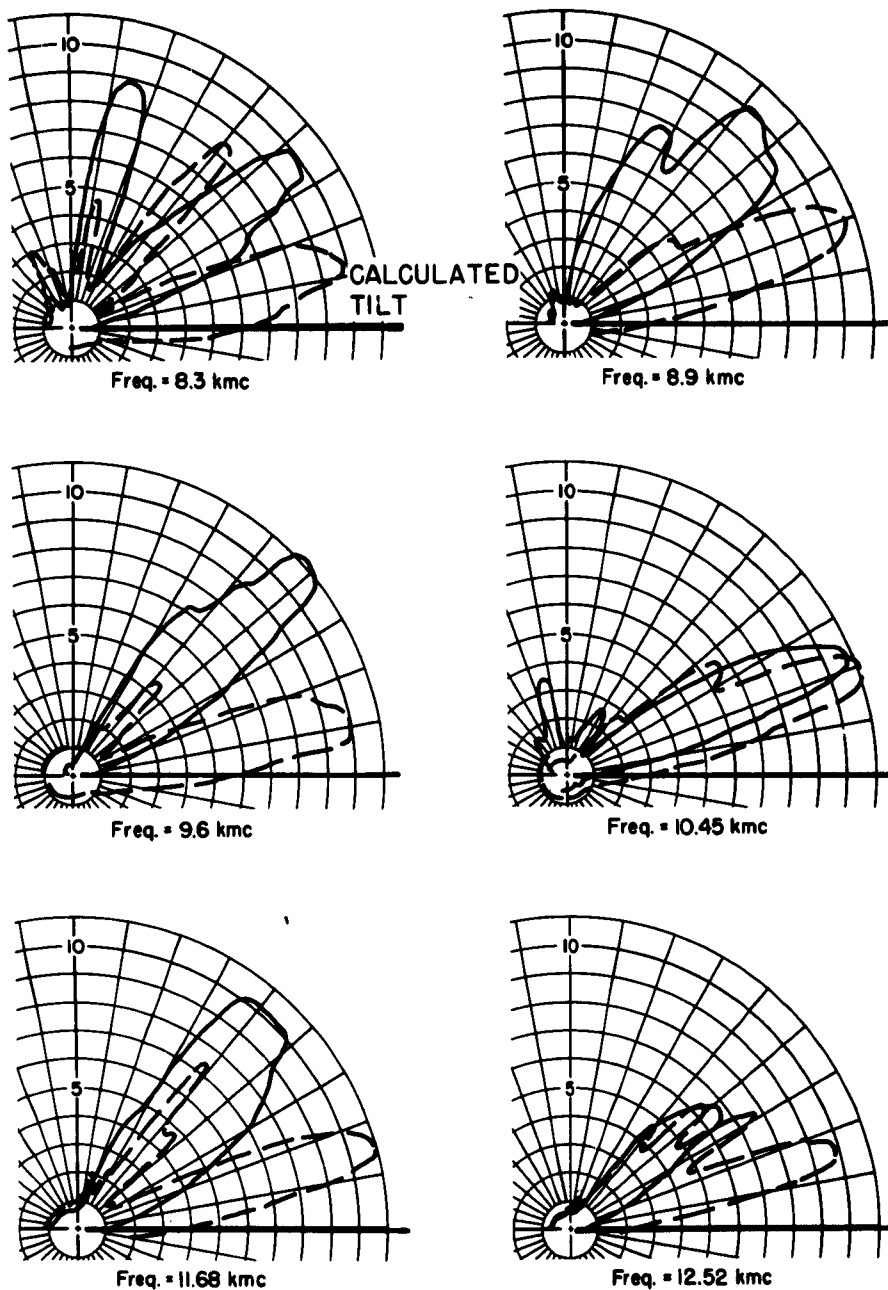ization of dashed patterns is in the plane of the pattern.

Fig. 17. Patterns of the tilted beam obtained with a 16.5° wedge with a dielectric constant of 20 in a 3.75" x 0.81" aperture fed by a 60° flare sectoral horn. Approximate calculated tilt = 90°. Polarization of the solid patterns is normal to the plane of the pattern. Polarization of the dashed patterns is in the plane of the pattern.
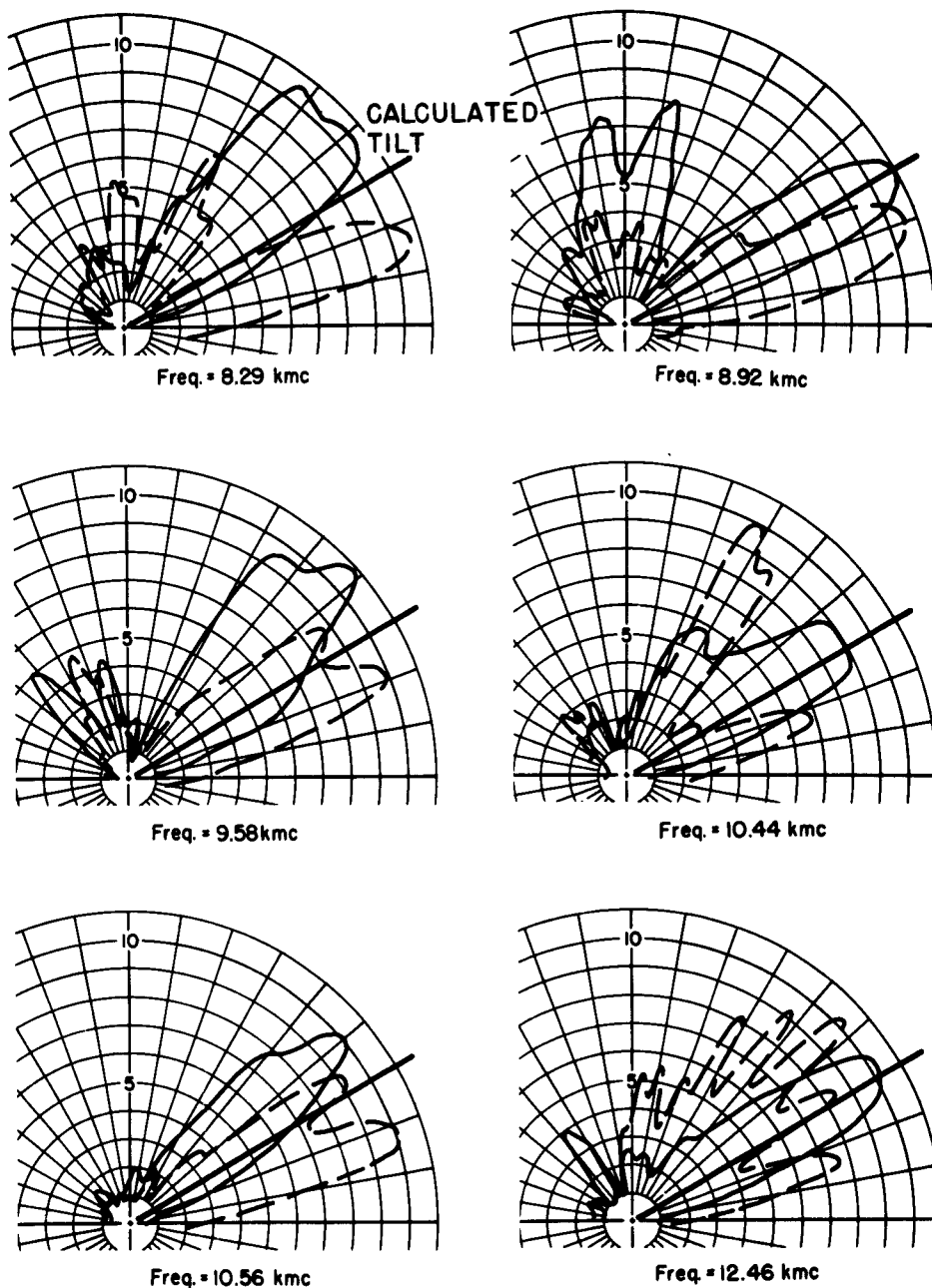
Fig. 18. Patterns of the tilted beam obtained with a curved lens
with a dielectric constant of 10 in a 3.75" x 0.81"
aperture fed by a 60° flare sectoral horn. Approxi-
mate calculated tilt = 60°. Polarization of the solid
patterns is normal to the plane of the pattern. Polar-
ization of the dashed patterns is in the plane of the pattern.

Fig. 19. Patterns of the tilted beam obtained with a 21° wedge
with a dielectric constant of 10 in a 2.81" x 0.81"
aperture fed by a 60° flare sectoral horn. Approxi-
mate calculated tilt = 52°. Polarization of solid
patterns is normal to the plane of the pattern. Polar-
ization of dashed patterns is in the plane of the pattern.

CALCULATED TILT

Freq. = 8.28 kmc

Freq. = 8.92 kmc

Freq. = 9.6 kmc

Freq. = 10.44 kmc

Freq. = 11.68 kmc

Freq. = 12.56 kmc
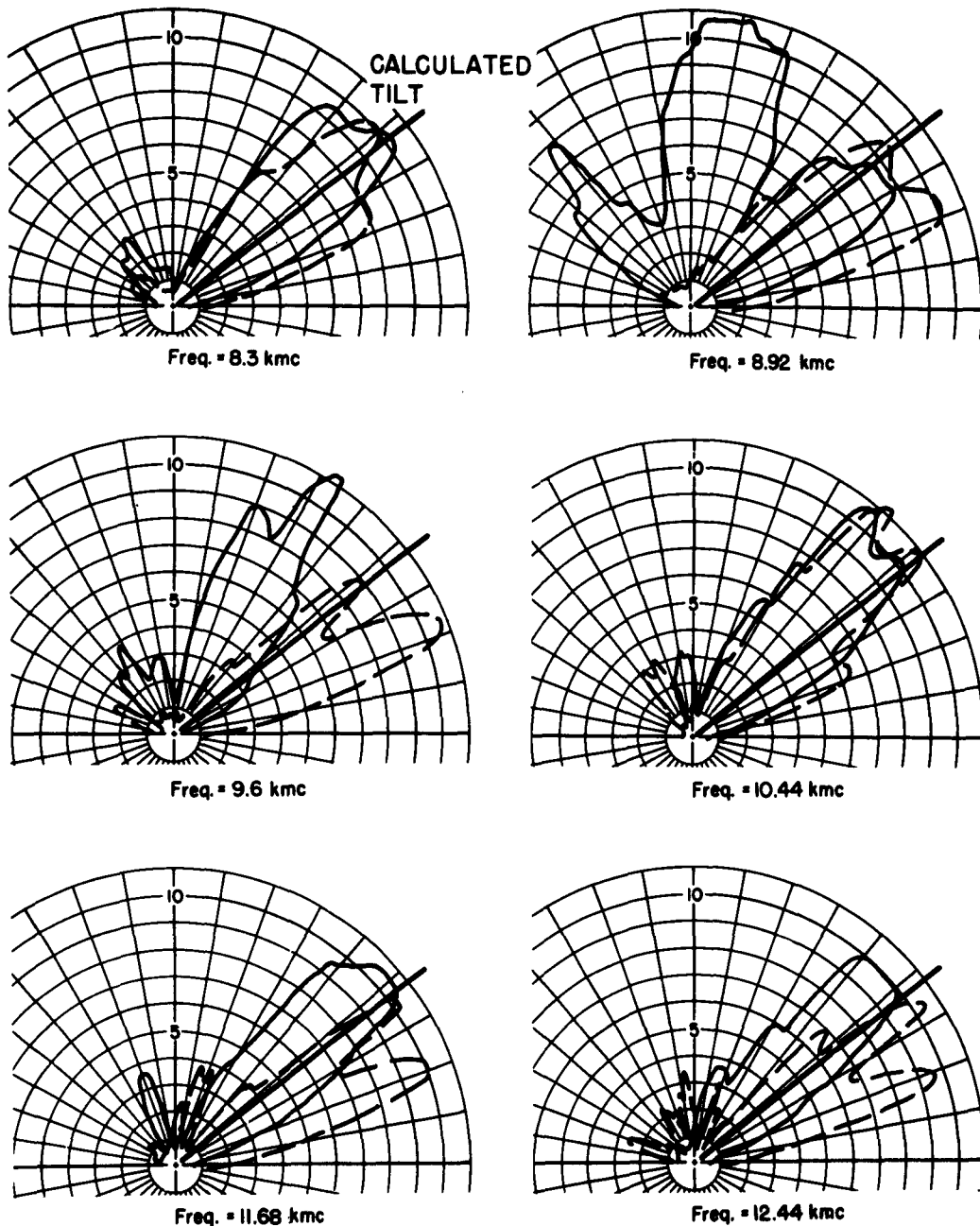
Fig. 20.   Patterns of the tilted beam obtained with a 16° wedge
with a dielectric constant of 15 in a 2.81" x 0.81"
aperture fed by a 60° flare sectoral horn. Approxi-
mate calculated tilt = 52°. Polarization of the solid
patterns is normal to the plane of the pattern. Polar-
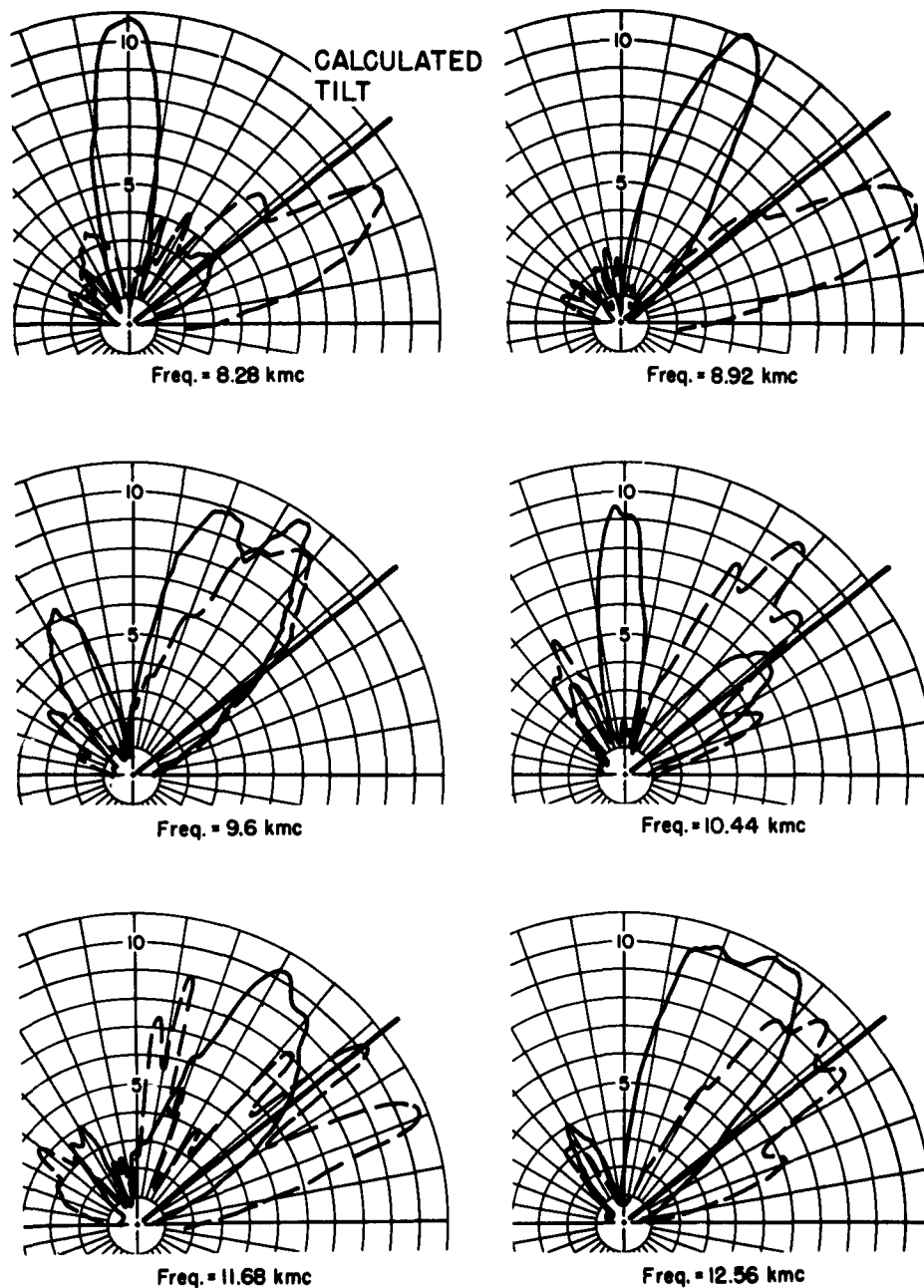ization of the dashed patterns is in the plane of the pattern.

Fig. 21. Patterns of the tilted beam obtained with a 13° wedge
with a dielectric constant of 20 in a 2.81" x 0.81"
aperture fed by a 60° flare sectoral horn. Approxi-
mate calculated tilt = 52°. Polarization of the solid
patterns is normal to the plane of the pattern. Polar-
ization of the dashed patterns is in the plane of the pattern.
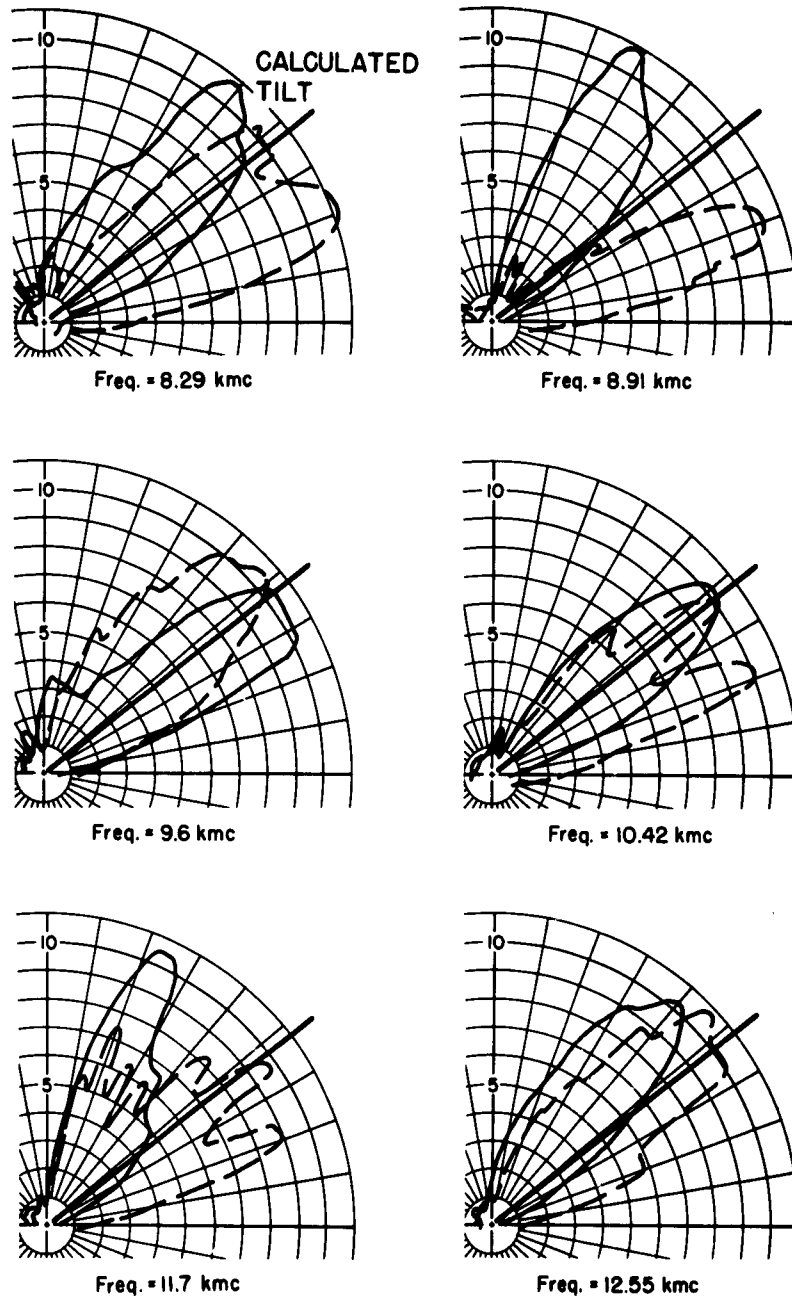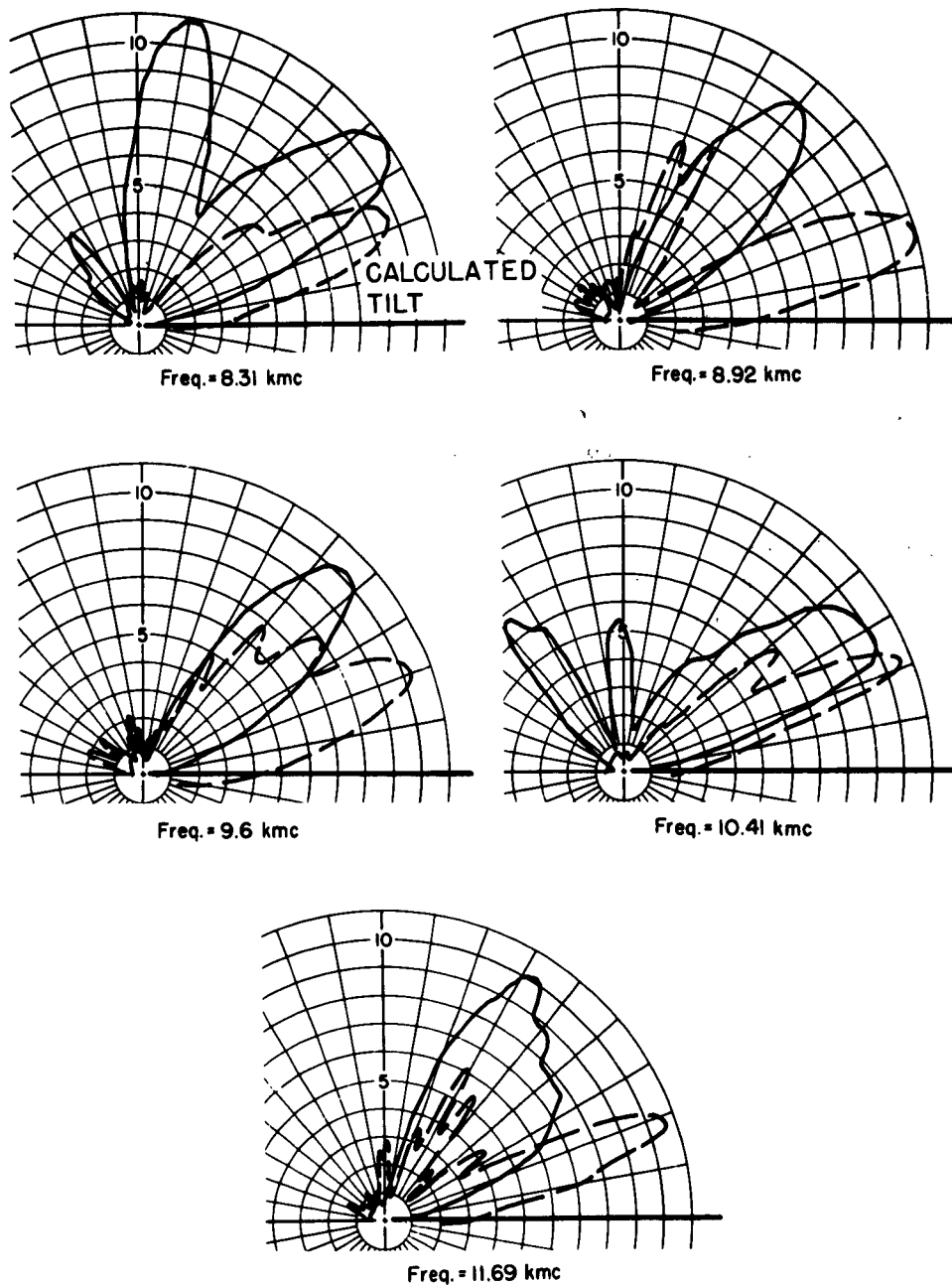
Fig. 22. Patterns of the tilted beam obtained with a 16.5° wedge with a dielectric constant of 20 in a 2.81" x 0.81" aperture fed by a 60° flare sectoral horn. Approximate calculated tilt = 90°. Polarization of the solid patterns is normal to the plane of the pattern. Polarization of the dashed patterns is in the plane of the pattern.

IV. BIBLIOGRAPHY

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[3] Interim Engineering Report 723-3, 12 May 1957, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Contract NOa(s)56-978 with North American Aviation, Inc., Columbus Division, Columbus 16, Ohio.

[4] Interim Engineering Report 723-4, 12 August 1957, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Contract NOa(s)56-978 with North American Aviation, Inc., Columbus Division, Columbus 16, Ohio.

NOTE: In submitting this report it is understood that all provisions of the contract between The Founda-
tion and the Cooperator and pertaining to publicity of subject matter will be rigidly observed.

Investigator _Harold N. Danvers_ Date _11/12/57_

Investigator _Robert J. Garbacz_ Date _Nov. 8, 1957_

Investigator _Chester E. Beachler_ Date _11-12-57_

Investigator _____ Date _____

Supervisor _T. E. Tice by R. C. Fouty_ Date _11/12/57_

For The Ohio State University Research Foundation

Executive Director _____ Date _____